Memo to File MN0057207 **February 25, 2016**

RE: U.S. Steel Minntac Tailings Basin – Sulfate in Sand River and Twin Lakes – SCRS impacts

From: Erik Smith

Purpose

This memo provides a five years post-mitigation review of the sulfate concentration and mass transport in the Sand River and Twin Lakes surface water drainage. The U.S. Steel Minntac tailings basin was constructed over the original wetland-complex headwaters of the Sand River in the late 1960's. In recent years, the headwaters consisted of identifiable seeps emanating from near the base of the tailings basin outer dam (e.g. SD002), as well as diffuse flow from wetlands along the east and northeast periphery of the basin. Monitoring and hydrologic data also suggest there are diffuse baseflow contributions to the Sand River, Admiral Lake, and the Twin Lakes (principally Little Sandy Lake) from groundwater that originates at the tailings basin. In 2010, a seepage collection and return system (SCRS) was installed along almost 9000 feet of the east basin perimeter. This system consists of French drains connected to pumped sumps, pumping wells, and shallow sheet piling and was designed to capture seepage that was reporting to the surface near the toe of the outer dam and return it to basin cell #2.

Data sources and limitations

This review uses data from the (roughly) monthly flow and sulfate concentration monitoring performed by U.S. Steel at the SW001 station on the Sand River (2000-2015) and the data collected in the Twin Lakes by the 1854 Treaty Authority from 2010-2015. Locations of key monitoring points are shown below in figure 1.

Any observations or interpretations made from the data should be done so with awareness of the following:

- these data are very limited in scope (i.e. one point in time per month);
- are being collected from a system that is highly variable on a time scale (days) that is much shorter than the monitoring interval (monthly), and;
- beaver activity upstream of this monitoring location has on occasion affected flow monitoring and could likely influence measured sulfate concentrations as well.

There has been a lengthy record of data collected at SW001 from which it's possible to develop an understanding of the range of sulfate concentrations and flow volumes that could be expected to occur at that location. The calculation of mass transport from a concentration and flow measurement provides a value that although useful, has potential to be non-representative if used to extrapolate mass transport over any time scale longer than that day. Sampling events separated by one week have changed enough in flow and concentration to cause an order of magnitude change in the calculated mass transport. Therefore, the equations representing trend lines on the graphs below have little value beyond a qualitative interpretation, and should not be considered to necessarily be accurate or predictive. Additionally, it has been noted that during some sampling events at SW001 during the winter months, flow measurement has not always been conducted the same day as sample collection. As a result mass transport calculations made during these months are particularly suspect, and therefore efforts to interpret changes in the Sand River post SCRS have relied more heavily on the months April through November. Unless otherwise noted, all concentrations are expressed in units of milligrams per liter (mg/L), flow is in million gallons per day (MGD) and sulfate mass transport is in kilograms per day (kg/day), calculated as the product of Concentration (mg/L) * Flow (MGD) * 3.785 liters/gallon.

Trends prior to SCRS

To better understand and interpret the effects of the SCRS on the Twin Lakes, this report will first describe the overall history of sulfate in the Sand River and at the nearest monitored seepage location SD002. Prior to construction of the SCRS there was a slight upward trend in the calculated sulfate mass transported in the Sand River at SW001 and a slight downward trend in the calculated mass discharged from seep SD002 (Figure 2). The calculation of mass at SD002 is likely to be more representative of tailings basin influences than for SW001 as the flow and concentration for the seep are much less variable and do not include significant watershed contributions. The increase in mass at SW001 appears to be the result of increasing flow, even while average concentration decreased slightly over the period of observation (Figure 3). Conversely, prior to the SCRS, the discharge volume from SD002 was decreasing slightly, while the measured sulfate concentration was increasing on average (Figure 4). As can be seen in Figure 2, the sulfate mass discharged from SD002 was only roughly one-tenth of the average mass transported past SW001. The remainder of the mass is from other documented, but unmonitored seeps and from baseflow. Figure 2 includes all available monitoring data and may have some sampling bias, since during the years 2002 to 2011, flow data was not collected as consistently during the winter months (roughly December – April) at SW001. Also, as was noted earlier, in recent winters sampling and flow measurement may not have been contemporaneous. To remove this potential bias and to allow for a more representative comparison of pre and post SCRS conditions, Figure 3 only includes data from April through November for each year. Table 2 shows all of the months for which a sulfate mass could be calculated.

Trends post SCRS

After the start up of the SCRS in 2010, monitoring data at SW001 show an overall decrease in average sulfate concentrations, but slightly increased flow (Figure 3). The difference in average flows is very small and if only the 5 years just prior to installation of the SCRS is considered, there is then a slight decrease in average flow post SCRS. The year 2003 had no snow pack, and consequently very low early spring flow, and this strongly affects the average values for the early portion of the data set.

Although, not shown here, analysis of the data indicates that the monthly stream flow is not correlated to monthly precipitation, although timing of snowmelt and operational changes in basin cells one and two water elevations likely have significant effects on the stream hydrology that would overprint any pattern that could otherwise be attributable to precipitation, making it difficult to discern. The slight increase in flow is more than offset by a large drop in concentration, causing a large decrease in the calculated sulfate mass being transported in the Sand River at SW001 after the SCRS became operational. Table 1 lists the maximum and average yearly sulfate concentrations at SW001 over the full year (Jan.-Dec.) as well as for the period May through October, as this corresponds to the sample period for the Twin Lakes monitoring. It's important to evaluate both these time intervals when comparing the Twin Lakes and SW001 data sets since the sulfate concentrations are typically much higher in the river system, and presumably the lakes also, during the frozen months when baseflow comprises most of the streamflow. It is notable that the maximum concentration for a year at SW001 never occurs in the months May through October. The maximum values for the years 2003 and 2007 seem anomolously high and above what could be hypothesized as the maximum possible concentration that could occur roughly 5 miles downstream from the basin given the typical basin sulfate concentration of about 900 mg/L. If these anomolously high values are disregarded, there appears to be a decrease in the maximum and average sulfate concentrations at SW001 post SCRS.

MPCA understands the operational design of the SCRS to be roughly 600 gpm of seepage intercepted and pumped back to the basin, but has little data on actual pumped totals. The June 2013 groundwater modeling report submitted on behalf of U.S. Steel by CRA included a table (table 6.2) indicated an estimated seepage return rate of 545 gpm based on measurements taken in 2010. Sampling of the SCRS by U.S. Steel in May of 2014 included instantaneous pumping rates from SCRS catch basin pumps 1 and 2 of 648 gpm and 294 gpm, respectively. Although data was not provided for the daily duration of pumping, these rates are not inconsistent with a 600 gpm daily average pumping rate. Sulfate concentrations from the two catch basins during the May sampling were 942 and 1070 mg/L. Using an average concentration of 900 mg/L and an average pumping rate of 600 gpm (0.864 MGD) gives an estimated sulfate mass recovery of slightly over 2900 kg/day. Table 2 provides mass calculations from each of the monthly monitoring events at SW001 where flow and sulfate concentrations were recorded. The sum of the sulfate masses for each of the years was calculated for the months of April through November, since this time period has the most complete and accurate data. Comparing the averages of these totals from the period before the SCRS was installed and after (Figure 5), shows a roughly 2922 kg/day reduction in mass after the system was installed (pre SCRS avg. of 6805 kg/day, post avg. of 3883 kg/day), which is a 43% decrease in mass transport. As mentioned earlier, drawing comparisons from once per month sampling on such a variable system should be done cautiously. A statistical analysis of the data was not done for this review but if it were, time series analysis would likely be best suited to this data. However, it is of note that the estimates for sulfate mass recovered by the SCRS (2900 kg/day) and the decrease observed in the Sand River (2922 kg/day) are in such close agreement.

Twin Lakes Monitoring

Results of the water quality and hydrology monitoring conducted by the 1854 Treaty Authority are well described in the annual summary reports published by that organization. One thing that is apparent from that monitoring program is that sulfate concentrations in the lakes have considerable temporal variability, often changing by 50% from month to month. To reduce some of the noise in the data, the average concentration at each location for the May through October sampling period for each year was calculated, and then plotted as the difference between that year and 2010. The year 2010 is not ideal as a comparison year since the SCRS was under construction and became operational in that year, but it is the earliest data available in the Twin Lakes showing some aspect of system behavior before the SCRS. Figure 6 shows that at all monitoring locations the average yearly concentration has been less for each of the years 2011 through 2015 compared to 2010. Although not shown here, the yearly maximum values at the Twin Lakes monitoring locations and SW001 are also all less than the 2010 maximums. As can be seen in Figure 6, the average values were sharply increased for the year 2015. There were only three sampling events in 2015 (June, August, and October), instead of the usual six, but the increase in the Twin lakes was consistent with what was observed at SW001 also. Water levels in the Twin Lakes for 2015 were just a bit below normal and precipitation was typical for the year, so there does not appear to be any hydrologic circumstance for the increase in concentrations. Thus, the cause(s) of this apparent discrepancy in 2015 values has not been determined.

Summary

Based on analysis of the available data, with the limitations acknowledged above, it has been observed that since the installation of the Sand River SCRS, average and maximum sulfate concentrations have declined in the Twin Lakes and Sand River, and mass transport has declined at the SW001 monitoring location. These observations are consistent with what would be expected when shallow emergent flow from the basin is intercepted prior to entering the drainage for this flow system. The estimated sulfate mass recovered by the SCRS (2900 kg/day) is similar to the observed decrease in mass at SW001 (2922 kg/day). Pre and post SCRS flow data are very similar. The SCRS reportedly intercepts approximately 0.86 MGD (not all of which would likely have surfaced), and the average April to November flow at SW001 is roughly 14 MGD. It does not appear that the SCRS has had a discernible impact on flow in the Sand River. Recent efforts at beaver control would be a confounding factor in attempts to interpret flow data. Unfortunately, there also isn't enough flow data for the winter months to evaluate the impact of the SCRS on frozen, low-flow conditions.

Prior to the SCRS, sulfate concentrations in the Sand River and Twin Lakes were greatest near the basin and decreased downstream. This trend has remained, but now with the reduction in sulfate mass coming from the source, average concentrations at all locations are less. Figures 6 and 7 show that, in general, monitoring locations closer to the basin experienced greater decreases in measured concentration, but the percent change in average concentration was least near the basin, and greatest farthest from it. This is consistent with the conceptual model of a stream where most of the pollutants are sourced from the headwaters area and this original solute mass becomes more dilute as the stream receives lower solute baseflow and surface inflows along its length. Whether the increased sulfate concentrations in 2015 are due to natural variability or to changes in system performance is unknown. U.S. Steel did perform a cleaning of the collection system piping in 2015, so the system may have been performing suboptimally prior to that. Given the lack of a downward trend in figures 6 or 7, and that the estimate of mass recovered by the SCRS is in agreement with the observed reduction downstream, it does appear, that as of this time, the full benefit of the SCRS on the Twin Lakes has been realized, and further decreases in sulfate concentrations beyond the range of natural variability in the system are not anticipated.

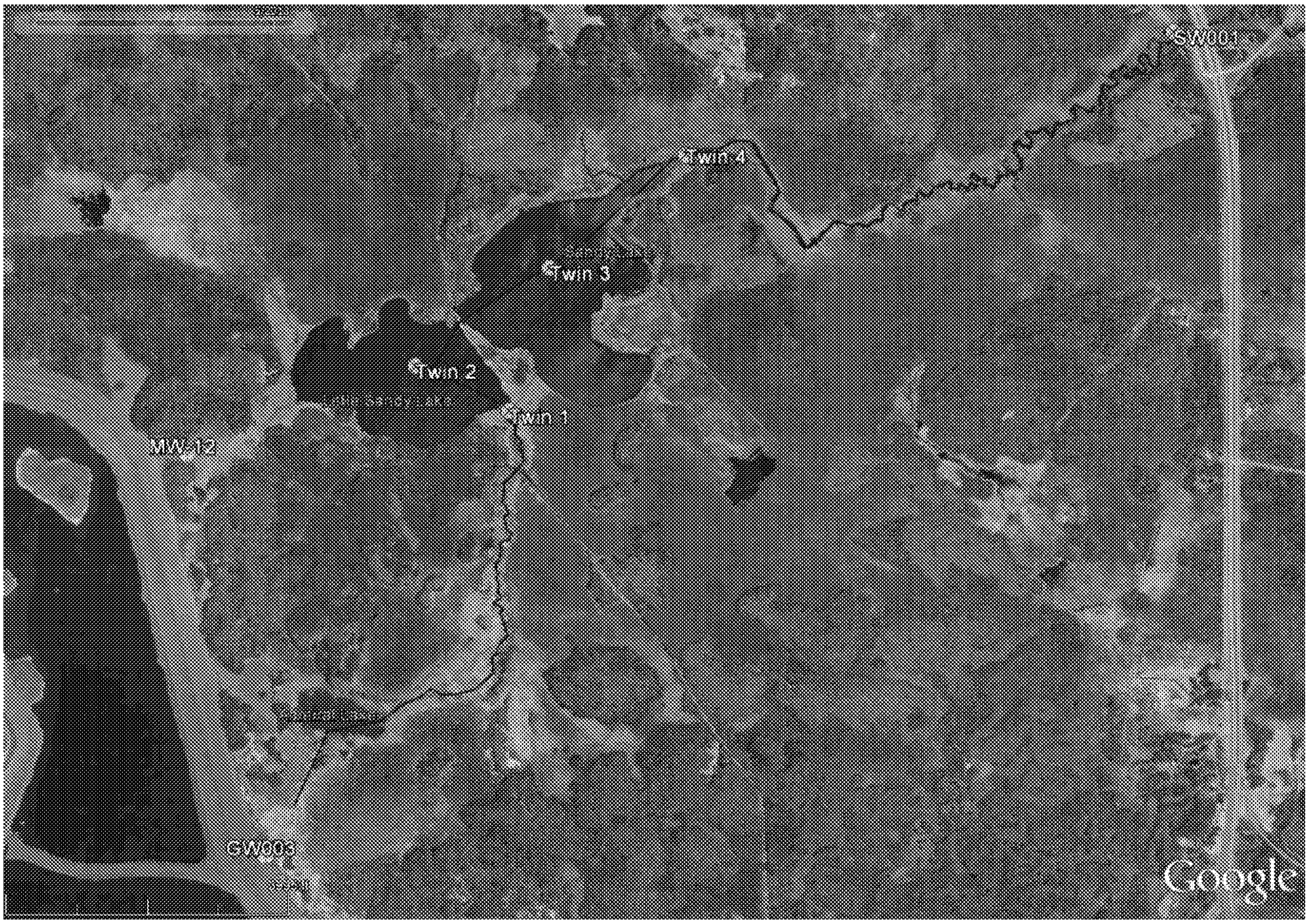

Figure 1: Key monitoring locations for the Minntac Tailings Basin and Sand River

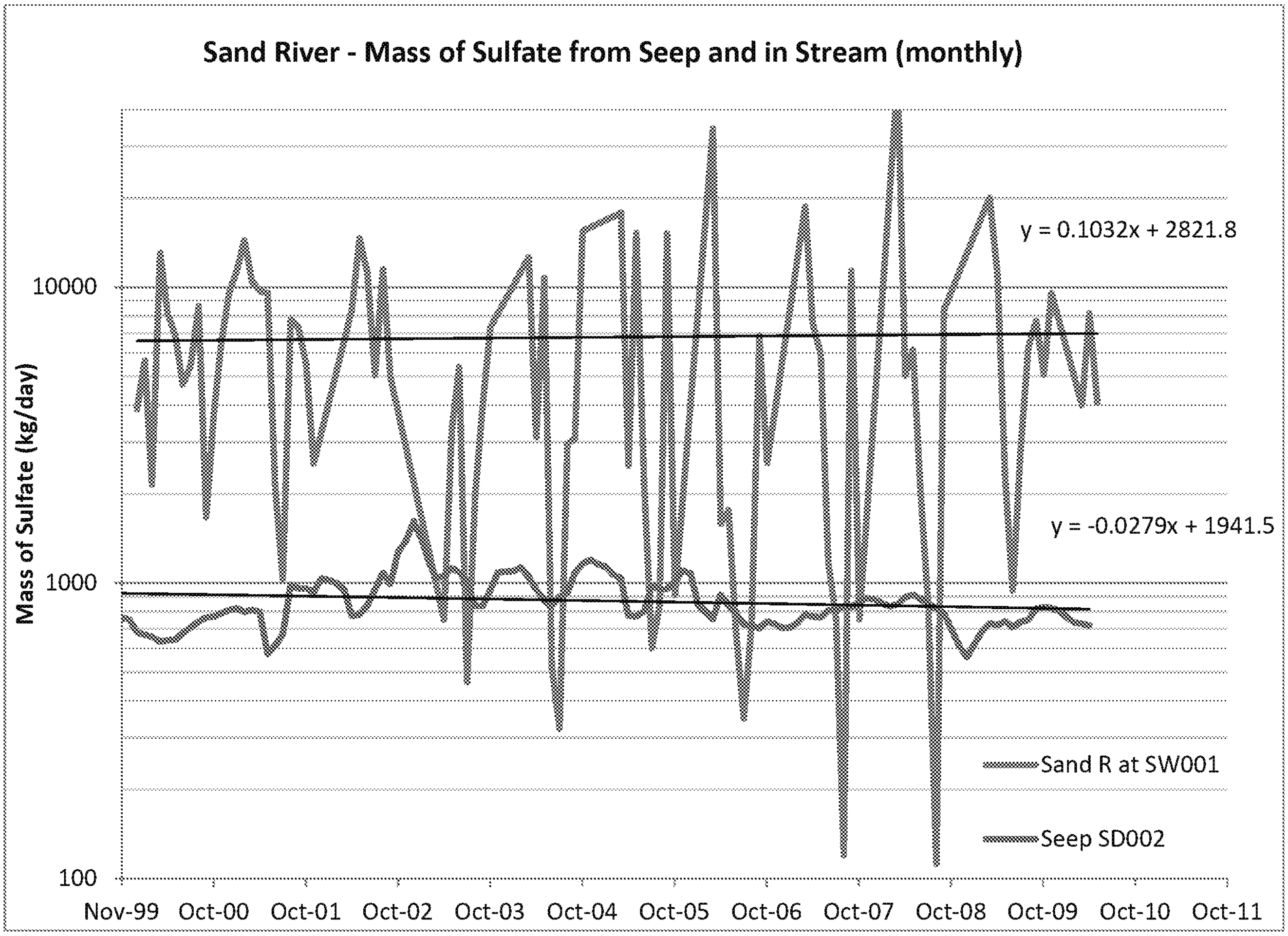

Figure 2: Pre SCRS sulfate mass at SD001 and SW001

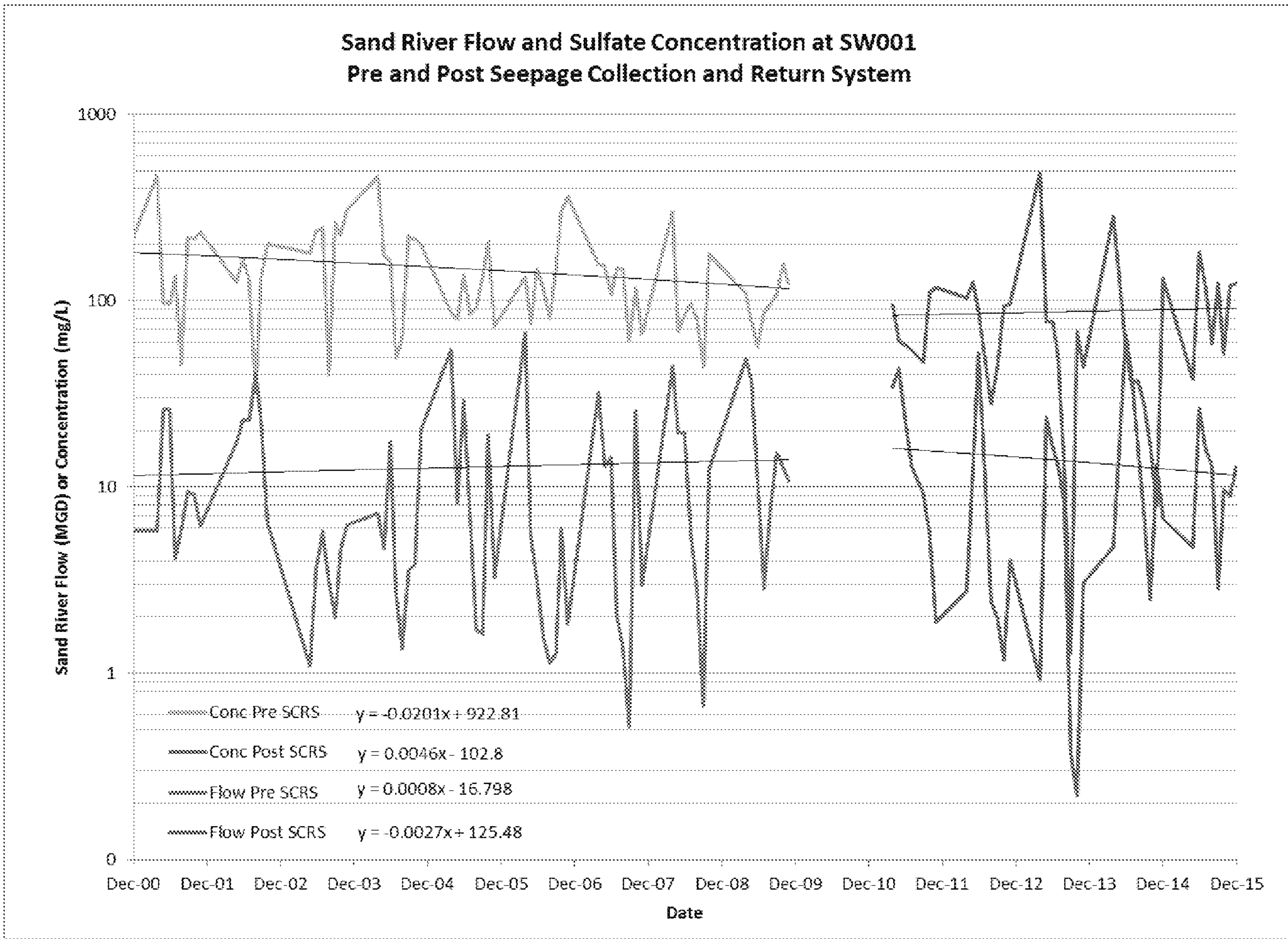

Figure 3: Sand River flow and sulfate concentration – Pre and post SCRS. Data is from April to November of each year (if available) only.

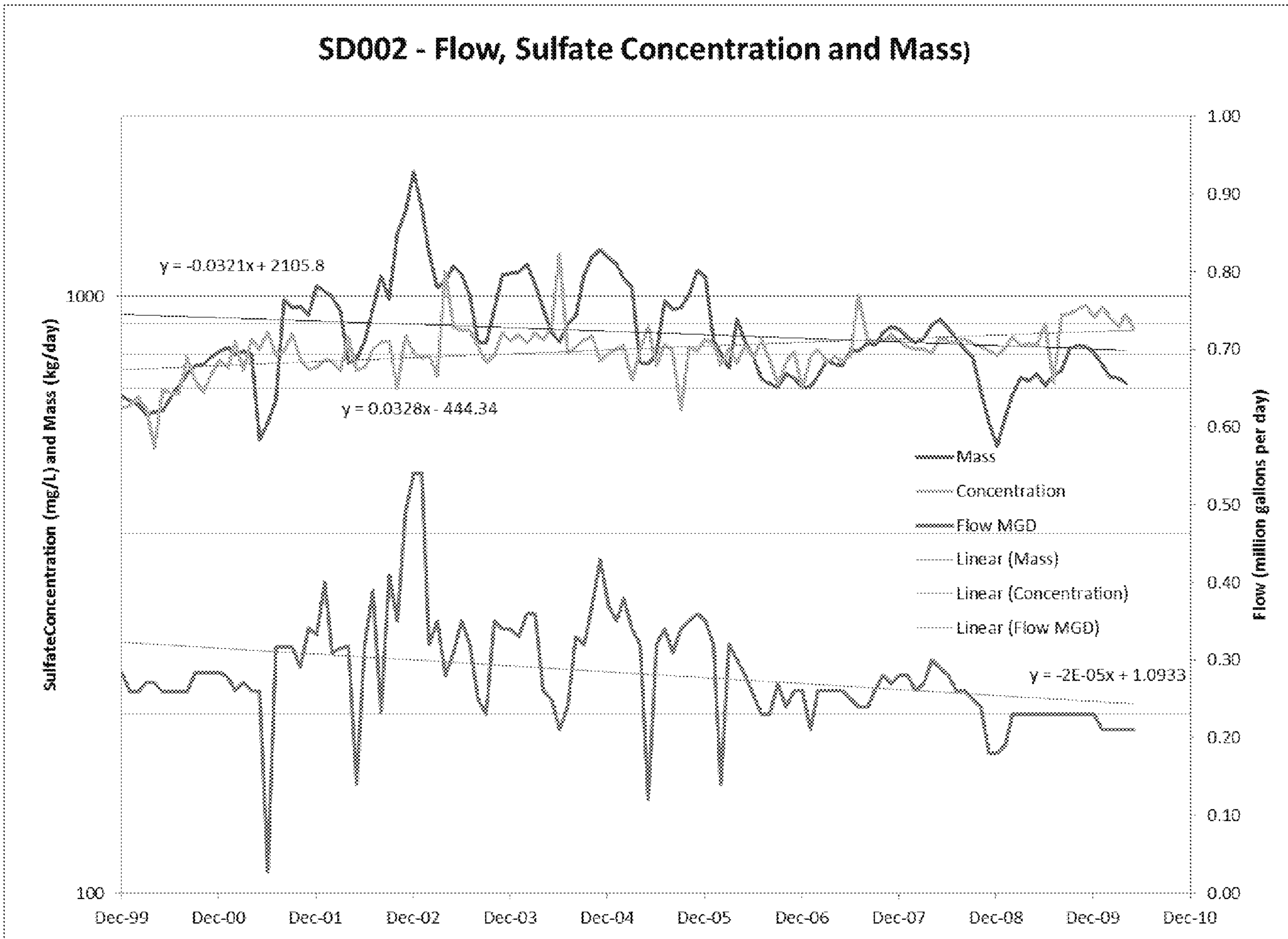

Figure 4: Monthly average discharge flow, sulfate concentration, and calculated mass at Seep SD002

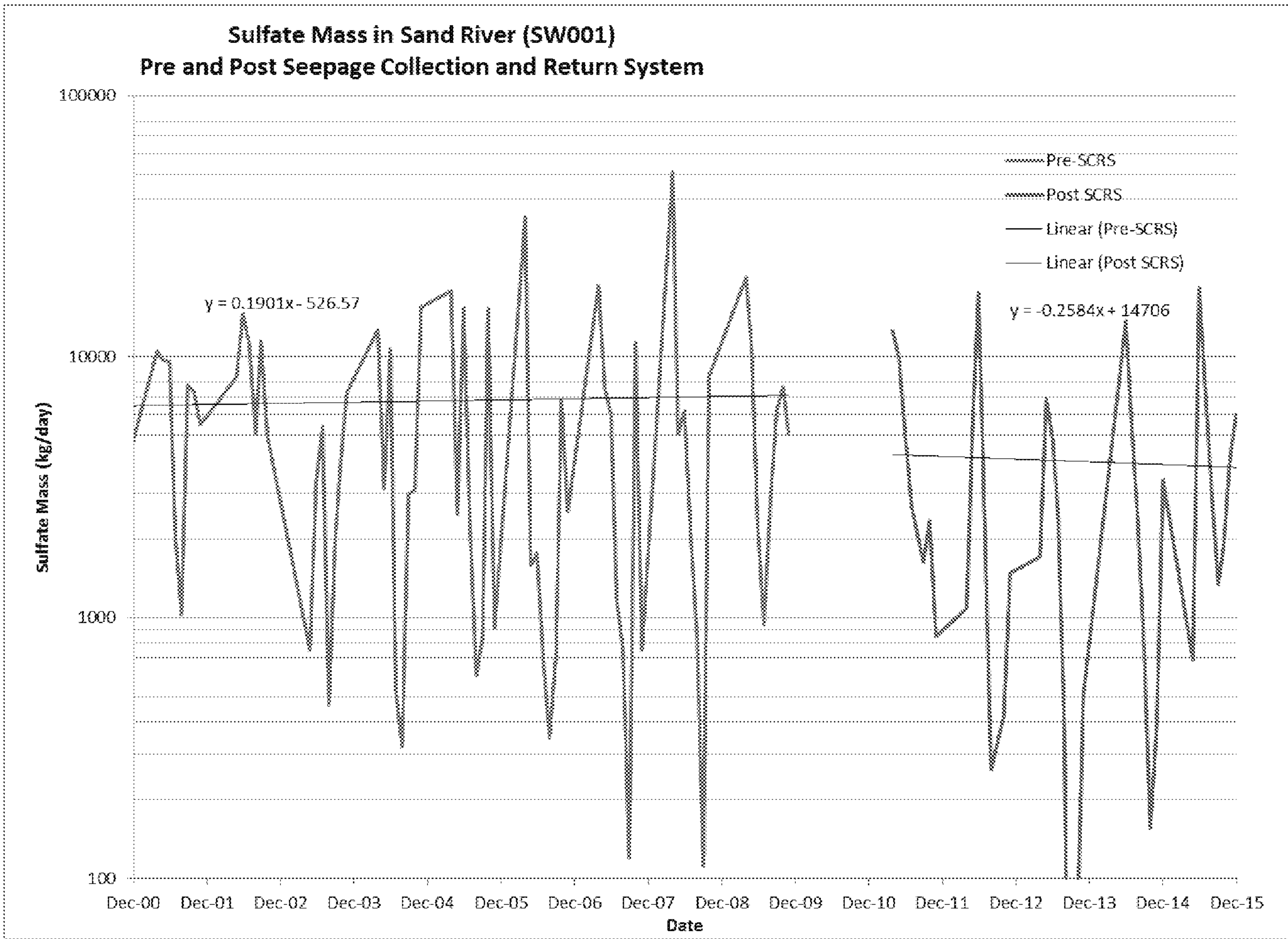

Figure 5: Calculated sulfate mass transport – pre and post SCRS. April – November data.

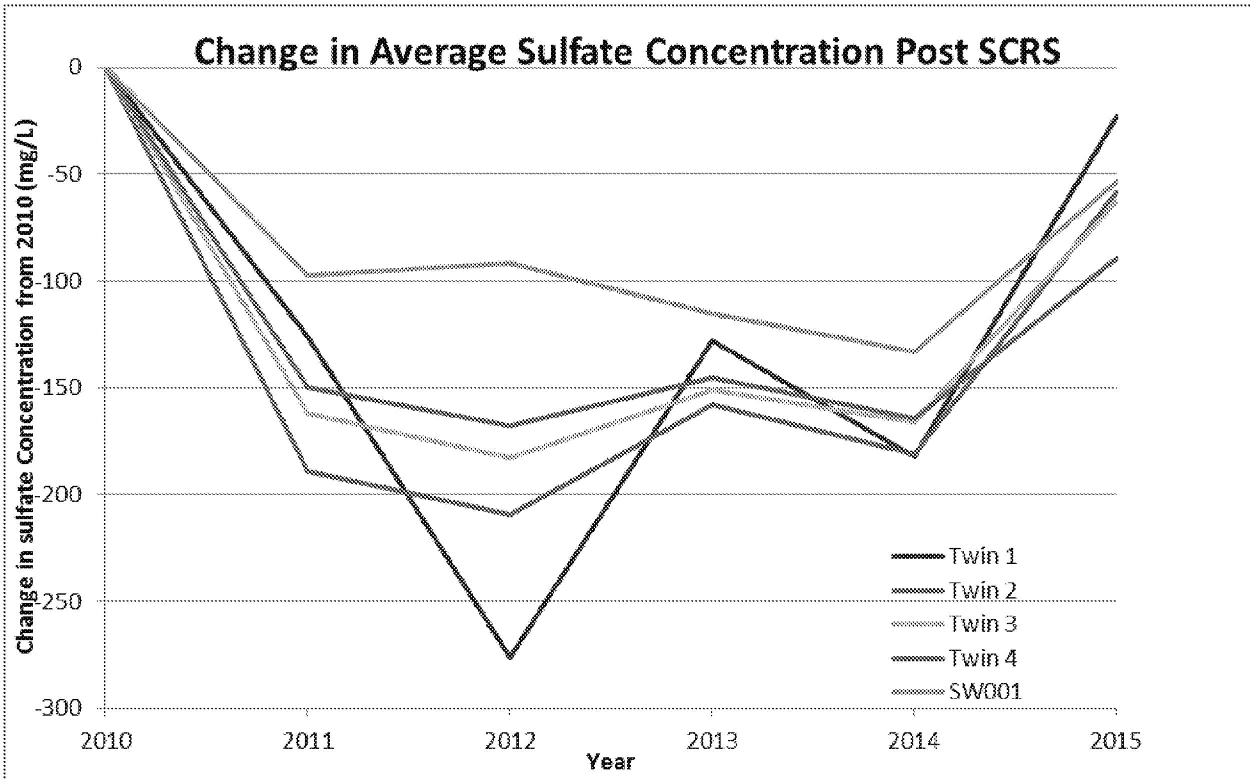

Figure 6: Change in yearly average (May-Oct.) sulfate concentrations with 2010 as baseline

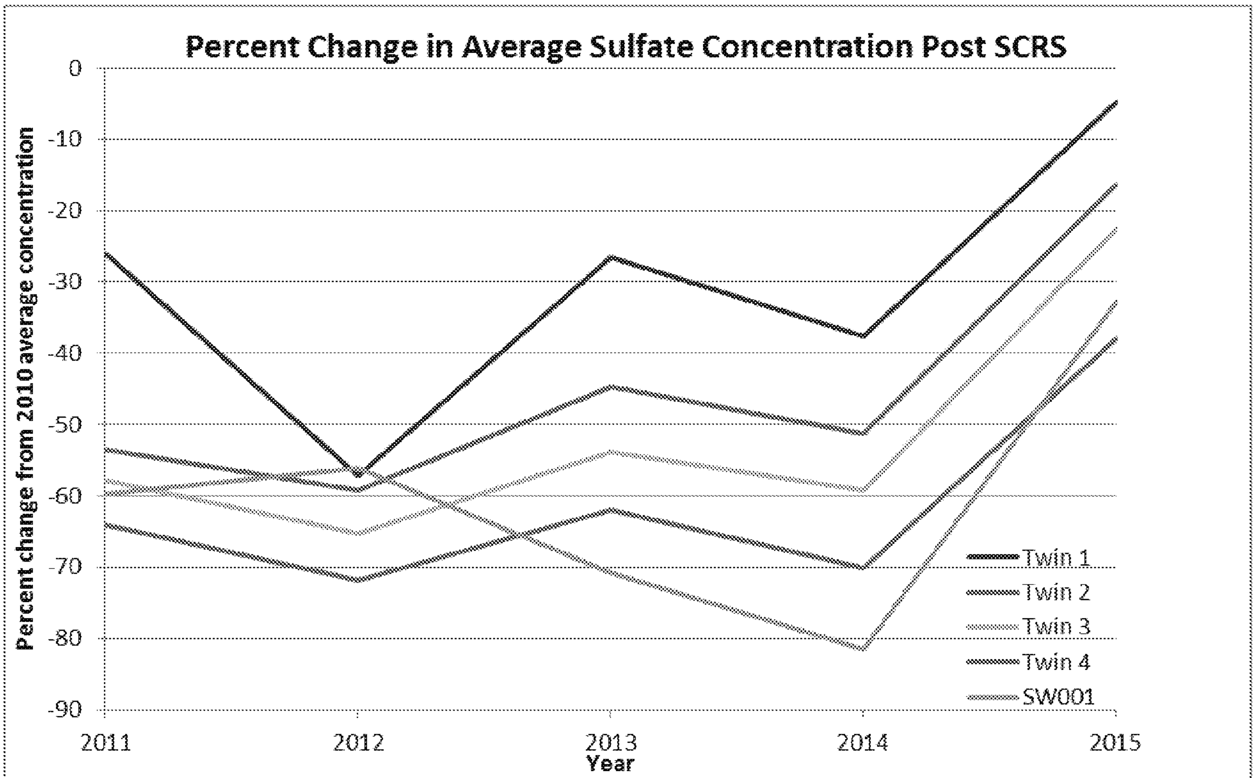

Figure 7: Percent change in yearly average (May-Oct.) sulfate concentrations with 2010 as baseline

	SW001 Sulfate Concentrations				Sulfate Mass
	Yearly Maximum		Yearly Average		April-Nov
Year	Full Year	May-Oct	Full Year	May-Oct	Avg. (kg/day)
2000	647	192	265	153	6,546
2001	653	218	270	135	6,688
2002	530	203	279	133	N/A
2003	803	263	352	199	N/A
2004	533	220	275	147	6,113
2005	528	210	224	124	6,931
2006	482	303	247	145	6,111
2007	958	154	280	123	5,809
2008	405	179	146	92	9,217
2009	496	158	194	97	7,023
2010	482	188	227	163	5,522
2011	233	111	121	66	4,386
2012	445	126	166	72	3,668
2013	490	77.4	177	48	2,102
2014	331	55	133	30	3,952
2015	563	183	183	110	5,305
Mean 2000-2009	**604**	**210**	**253**	**135**	**6805**
Mean 2011-2015	**412**	**110**	**156**	**65**	**3883**
% Diff. Post SCRS	**-31.7**	**-47.4**	**-38.4**	**-51.8**	**-42.9**

Table 1: Yearly maximum and average sulfate concentrations and sulfate mass at SW001

Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg 00-09	2010	2011	2012	2013	2014	2015	Avg 11-15
Jan	3,868	9,643									6,755				2,293	2,598	1,407	2,099
Feb	5,657	11,430									8,544			2,948	3,465	2,428	1,830	2,668
Mar	2,153	14,409									8,281			2,832	1,685	6,014	3,836	3,592
Apr	13,080	10,495			12,668	17,852	34,398	18,777	51,154	20,174	22,325	3,997	12,546	1,084	1,706	5,156	690	4,237
May	8,184	9,680	8,374	752	3,107	2,486	1,582	7,578	5,019	11,044	5,780	8,173	10,004	6,071	6,898	13,740	18,286	11,000
Jun	6,864	9,572	14,638	3,292	10,747	15,336	1,765	5,927	6,163	2,220	7,653	4,084	5,027	17,533	4,805	5,686	7,146	8,039
Jul	4,690	2,138	11,194	5,385	521	2,190	685	1,175	2,046	941	3,096	6,788	2,676	2,161	2,469	2,356	2,920	2,516
Aug	5,435	1,024	5,036	461	321	601	348	762	838	2,800	1,763	4,841	no flow	261	370	755	1,348	684
Sep	8,648	7,781	11,539	1,991	2,964	844	722	120	112	6,254	4,098	2,144	1,635	333	2	156	1,887	803
Oct	1,671	7,336	4,979	3,969	3,076	15,229	6,847	11,381	8,401	7,685	7,057	6,628	2,353	419	57	392	4,104	1,465
Nov	3,795	5,478		7,321	15,503	907	2,542	754		5,069	5,171	7,523	849	1,481	509	3,377	6,054	2,454
Dec	6,554	2,538								9,593	6,228		1,107	2,711	1,276	2,511	6,644	2,850
Median	6,149	7,559	9,784	3,292	3,091	2,338	1,674	3,551	5,019	5,662	4,812	5,734	2,676	1,282	1,108	2,867	3,512	2,289
Mean	6,546	6,688	9,293	3,310	6,113	6,931	6,111	5,809	10,533	7,023	6,836	5,522	5,013	3,668	2,102	3,952	5,305	4,008
Sum (Apr-Nov)	52,367	53,505			48,907	55,446	48,888	46,474	73,732	56,187	54,438	44,178	35,090	29,342	16,816	31,618	42,436	31,061

April - November		
Pre SCRS	54,438	Average of April-November Sum for years 2000, 2001, and 2004-2010
Post SCRS	31,061	Average of April-November Sum for years 2011-2015
	43%	Percent reduction in Summed mass Post SCRS
	2,922	Average mass (kg) reduction per month post SCRS

Table 2: Calculated daily sulfate mass (kg/day) at Sand River monitoring location SW002